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WHITE NOISE LOADING

OF

MULTI-CHANNEL COMMUNICATIONS SYSTEMS

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A. GENERAL

A.1 INTRODUCTION.

When a large number of telephone channels are to be carried by coaxial cables or by a broad band radio relay link, it is now a universal practice to use frequency division multiplexing with 4kc channel spacing for base-band loading of the system. The number of channels provided is usually an integral multiple of twelve.

The resulting multiplex signal comprises many rapidly changing components of various frequencies and if any non-linear distortion in the transmission system exists, this will introduce unwanted intermodulation products of these components. When distortion is severe, unwanted products are heard by the telephone subscriber as a background signal resembling random noise. These spurious noise products are measured with a psophometer in, or related to, a telephone test channel in picowatts (pW) with weighting applied to approximate to the relative interfering effect of various frequency components. (Note: $1pW = 10^{-12}$ watts).

Standards of transmission performance for long distance radio circuits have been suggested by CCIR and DCA; for long distance cable circuits by CCIF. For the purposes of this article, the most important of these standards are the recommendations for 2500 kilometer (1562.5 miles) and 6000 nautical mile telephone circuits. The 2500km recommendations state that the noise measured at a point of zero relative level in any audio channel shall not exceed 10,000pW psophometric for more than one percent of the busy hour. Of this total, 2500pW is alloted to the terminal multiplexing equipment and the remainder (7500pW) is the maximum allowed for all forms of noise and intermodulation introduced in the transmission path.

The DCA 6000 nautical mile recommendations state that the spurious noise should not exceed 25,000pW psophometric during the busiest hour in a month of poorest transmission. Of this total, 20,000pW is assigned to the transmission equipment and 5,000pW to the multiplex.

These recommendations provide an excellent method of specifying performance from an individual telephone user's point of view, but they are quite impractical for a precise specification of equipment performance, for acceptance testing of new systems, or for general routine testing. For these purposes, the spurious noise requirements must be translated into a test method which can be carried out rapidly under accurately controlled conditions with repeatable results.

The method now being internationally used is to load up the baseband of the equipment with random noise to simulate traffic conditions, to introduce perhaps three quiet slots in the noise spectrum at the transmitter and to measure, at the receiving terminal, the resulting noise in the slots due to distortion and propagation effects. This is commonly called White Noise Loading.

A.2 NOISE MEASURING UNITS.

The decibel is commonly used in the communications industry to express a ratio between two quantities of power. Neither quantity needs to be defined to express the ratio in decibels or dB, and for many purposes, a knowledge of the ratio alone is sufficient. For example, the gain of a linear amplifier or the attenuation of a pad can be expressed in decibels

without knowing either the input or output power of the device. Frequently, however, there is a need to know the ratio between signal (or noise) power at some point in a circuit and some fixed, known quantity of power. In this case, it is customary to express the ratio as so many dB above or below the reference power.

The most common reference power used in the telephone industry is one milliwatt. Because signal power is almost always undergoing attenuation (a division process) or amplification (a multiplication process) the expression of power directly in watts or milliwatts would often require lengthy and cumbersome calculations. A more convenient method of indicating an amount of power is to express it as being so many dB above or below a reference power of one milliwatt, since adding and subtracting decibels provides the same result as multiplying and dividing power. Because of its widespread usage, "decibels above or below one milliwatt" is usually abbreviated dBm.

In addition to dBm, there are several other logarithmic units in use in the telephone industry which are expressed as dB above or below some reference power. The most important of these are dBa, dBrn, dBx and vu.

dBa and dBrn (formerly written dB-RN) are used to indicate the actual interfering effect of noise in a communications channel, by relating it to the interfering effect of a fixed amount of noise power or reference noise; dBx is a unit for expressing crosstalk coupling on transmission lines; vu is used to designate the ratio between the "volume" (or loudness) of spoken or musical sounds and a reference volume.

dBa and dBrn

dBa and dBrn are closely related units; in fact, the abbreviation dBa means, effectively, dBrn adjusted. Both terms originated from research conducted by the Bell Telephone Laboratories and the Edison Electrical Institute to determine the transmission impairment caused by noise interfering with speech. Since noise may consist of random frequencies with widely varying amplitudes, it was necessary to evaluate the interfering effects of single frequencies or relatively narrow bands of frequencies, to obtain usable data.

A large number of listening tests were made with different tones introduced as interference. The degree of interference was determined by comparing the power of each tone with the power of a 1000-cycle tone creating the same degree of interference. For example, if the interfering effect of a particular tone was to be determined, that tone was superimposed on a specially selected conversation at a reference power level. When the interfering tone was removed, a 1000-cycle tone was superimposed on the same conversation and its power level adjusted until the listener judged that it had the same interfering effect. The difference noted between the power levels of the selected tone and the 1000-cycle tone was then considered to be the difference in interfering effect.

When this same test was performed for a number of different tones in the voice frequency spectrum and for a number of different listeners using the same apparatus, it was possible to plot a graph showing the relative interfering effects of different frequencies in the voice frequency spectrum compared to 1000-cycles. Such curves are called weighting curves. With this information available it was possible to construct

equalizing networks such that each component frequency of the voice frequency spectrum was attenuated in the same manner as it appeared to be attenuated by the average ear with the listening test apparatus. By using these equalizers in conjunction with a suitable amplifier, rectifier and DC meter it was further possible to measure electrically the interfering effect of any frequency or combination of frequencies.

Since any noise or tone superimposed on a conversation has an interfering effect, it was desirable to express all quantities of interfering effect in positive numbers. To accomplish this, a power of 10^{-12} watt or -90dBm at 1000 cycles was selected as the reference power because a 1000-cycle tone having a power level of -90dBm appeared to have negligible interfering effect. Therefore, all other noise powers likely to be encountered would have a positive interfering effect that could be expressed in dB above reference noise of -90dBm at 1000 cycles or, in abbreviated form, as dBrn.

These early experiments and tests to evaluate the interfering effect of noise were made with Western Electric Type 144 handsets and resulted in the 144 weighting curves in Fig. 1.

F1A Weighting

Later, an improved type of handset (Western Electric Type F1A) came into general use with a type F1 transmitter and HA1 receiver. This equipment was less sensitive at the 1000-cycle reference frequency, but had a more uniform frequency response. When tests similar to those used for 144 telephone sets were conducted with this handset, the weighting curve shown was obtained and designated F1A weighting. The tests indicated that the new handset gave approximately a 5dB improvement over the electrical and accoustical performance of the 144 handset when using line weighting.

Because of the differences in sensitivity and frequency response, noise measurements with the F1A weighting provided indications about 5dB higher than with the 144 weighting. Rather than change existing standards, a new reference noise power of -85dBm ($10^{-11.5}$ watt) was introduced which produced identical noise measuring set readings for equal transmission impairments. The change in reference noise power necessitated a change in the units used to express interfering effect and resulted in the adoption of a new unit called dBa -- which means "decibels adjusted".

'C' Message Weighting

Recently, a newer line weighting was introduced in the Bell System, reflecting the performance of more recent equipment. As in the change from 144 weighting to F1A weighting, the new characteristic - which is called C-message weighting - has required a change in the noise power to which it is referred. Since the new equipment improves on the older equipment, an even higher reference power than the -85dBm F1A reference would be required to express equal interfering effects with equal numbers. Since this might have resulted in some measurements having to be made in terms of "negative" values of noise, the original -90dBm (10^{-12} watt) reference power was reinstated. Interference measured with this weighting is expressed in "dBrn C-message" units to distinguish it from the earlier "dBrn 144-line".

CCIF Psophometric Weighting

The international standard telephone weighting characteristic is called the CCIF psophometer curve.

If flat 3kc noise is to be measured the results obtained with the CCIF curve will be very similar to that measured with an F1A weighting filter

because the areas under the two curves are almost equal although their shape is not precisely the same.

The biggest difference between the two characteristics is their reference frequency. The F1A reference is 1kc while the CCIF reference is 800cps. Psophometric weighting is designated by the suffix 'p', ie. dBmp, pWp, etc. Psophometric measurements do not relate to a standard noise reference (-85 or -90dBm); they refer to actual noise power measurements such as dBmp (dB relative to 1mW with psophometric weighting) or pWp (picowatts psophometrically weighted, 1pW = 10^{-12} watts).

Noise Measurements

Previously all noise measurements made with either 144 or F1A weighting have been expressed in dBa, since, when using 144 weighting, dBa and dBrn are numerically equal, represent the same amount of noise power, and have the same interfering effect. This is not true of dBrn C-message, however. Although the same reference noise power is used as in 144 weighting, the broader frequency response of C-message weighting results in much less noise power being attenuated by the weighting characteristic. Thus, a 3kc band of uniform noise is attenuated 8dB by the 144 weighting characteristic, 3dB by the F1A or CCIF weighting, but only 1.5dB by the C-message weighting.

Where the noise is known to be evenly distributed across a 3000-cycle voice frequency band, measurement can be made with a suitable transmission measuring set or AC voltmeter. Because the weighting networks attenuate various frequencies differently, one milliwatt of evenly distributed noise (flat noise) produces only 82dBa of interfering effect with 144 and F1A weighting. Therefore, measurements of flat noise in dBm can readily

be converted to dBa by adding 82 to the reading (eg. -50dBm +82 = +32dBa). In the case of C-message weighting, however, noise power is calculated by adding 90 -1.5, or 88.5 to the flat noise power. If noise power is again -50dBm, Noise = -50 +(90 -1.5) = 38.5dBrn C-message.

In case of measurements made at 1000cps (800cps with CCIF weighting), it is only necessary to make a comparison with the reference power, since there is no weighting effect on a 1000cps tone. Thus, a 1000cps signal having a power of 0dBm would yield 90dBrn (144 line), 85dBa, and 90dBrn (C-message).

Although these conversions are quite straightforward for 1000-cycle tones and flat noise, conversion of other types of noise power to meaningful noise terms may become quite complicated. Noise, as found in transmission lines and electronic apparatus, varies widely as to its component frequencies and their relative amplitudes. It seldom consists of a single frequency. The chief source of noise in open-wire voice frequency circuits is induction from power lines and apparatus.

In open-wire carrier systems, noise comes from a variety of sources including power lines, atmospheric disturbance and interference from radio transmitters. While cable and microwave radio relay circuits are not subject to any great degree of noise from atmospherics or power lines, the chief sources of noise are intermodulation distortion, crosstalk, etc. Noise at carrier frequencies is often distributed evenly across a channel bandwidth. In open-wire voice frequency circuits, however, noise is more often concentrated at certain frequencies, usually odd harmonics of the local power frequency.

Single interfering frequencies other than 100-cycles can also be measured in dBm and converted to dBa by use of the weighting curves. For example,

if a 300-cycle interfering tone is measured to be -40dBm, the F1A line weighting curve shows that it is 15dB less interfering than a -40dBm, 1000-cycle tone; in other words, its interfering effect is the same as that of a 1000-cycle tone of -55dBm. A -55dBm, 1000-cycle tone is equivalent to 30dBa. Therefore, the -40dBm, 300-cycle tone has an interfering effect of 30dBa.

Volume Units

Where programs and certain other types of speech or music are being transmitted, monitoring of the program volume level is necessary to maintain a constant average volume. Failure to maintain the program volume level constant may cause overmodulation of line amplifiers or radio transmitters and cause distortion in listeners' loudspeakers or handsets. If a simple dB meter or voltmeter is bridged across the circuit to monitor the program volume level, the indicating needle will try to follow every fluctuation of program power and will be difficult to read and will have no real meaning. Also, different meters will probably read differently due to differences in their damping and ballistic characteristics.

To provide a standardized system of indicating volume, a special instrument and set of units were created. These instruments are called VU meters or volume indicators and the units of measurement are volume units or vu. Ordinarily, volume can be measured in vu only on these special instruments because the volume unit is based on the readings of these instruments under a specified set of conditions. One exception to this rule is the Western Electric 2B Noise Measuring Set which can be calibrated to read in vu.

The latest Western Electric noise measuring set is Type 3A. This instrument is calibrated in dBrn with either 'C' message or flat 3kc weighting. The indicating instrument used in vu meters is a DC milliammeter having a

slow response time and damping slightly less than critical. If a steady sine wave is suddenly applied to the meter, the pointer will move to within 99% of its steady state value in 0.3 seconds and overswing the steady state value by 1.0 to 1.5%.

A standard volume indicator (meter and associated attenuator) is calibrated to read 0vu when connected across a 600 ohm circuit carrying 1 milliwatt of sine-wave power having a frequency between 35 and 10,000cps. For complex waves such as speech a vu meter will read some value between the average and the peak values of the complex wave. There is no simple relation between the volume measured in vu and the power of such a complex wave. The actual reading will depend on the particular wave shape. For steady sine waves within the frequency range of the instrument, the reading in vu will be equal to the reading of a dB meter in dBm connected across the same circuit.

dBa0, dBm0 and dBm0p

The above abbreviations are coming into widespread use in microwave and carrier systems to express noise and signal power in terms of the levels that should exist at a so called zero transmission level point (0 TLP).

The term dBa0 is a measure of noise power with reference to zero dBm at the Reference (zero) Transmission Level Point. Noise powers measured at any Transmission Level Point can be expressed in dBa0 by correcting the noise power measured for the difference in level between the point of measurement and the Reference Transmission Level Point. The relative noise power in dBa is obtained from a power measurement of noise using F1A weighting.

Example: A noise measurement of +20dBa measured at a -4dB transmission level point is equivalent to +24dBa0.

The term dBm0 is a measure of power with reference to zero dBm at the

reference transmission level point (RTLP). Powers measured at any transmission level point can be expressed in dBmO by correcting the power measured for the difference in level between the point of measurement and the Reference Transmission Level Point.

Example: (1) A tone of +36dBm measured at a +19dB transmission level point is equivalent to +17dBmO.

(2) A tone of +17dBmO is equivalent to +7dBm measured at a -10dB transmission level point.

The term dBmOp refers to power measured in dBmO with psophometric weighting.

Other Units

Various other units are also used in the telephone industry and other sections of the communications field. They include dBx, dBw, dBRAP, dBv and others. Of these, dBx is the most common in the telephone industry.

dBx is used to indicate crosstalk coupling in telephone circuits, like dBa and dBrn, it may be measured with a noise measuring set. dBx means decibels above reference coupling. Reference coupling is defined as the coupling necessary to cause a reading of OdBa on the disturbed circuit when a test tone of 90dBa is impressed on the disturbing circuit. Both values of dBa are for the same weighting.

Concerning the other units mentioned above, dBw are decibels referred to one watt while dBk are decibels referred to one kilowatt. Both dBw and dBk are often used to indicate radiated power from radio transmitters. dBRAP indicates decibels above reference acoustical power which is defined as 10^{-16} watts. dBv designates decibels referred to one volt. Other logarithmic units in use are similar to these mentioned.

A.3 DEFINITION OF NOISE MEASURING UNITS.

1. dBa — (dBrn adjusted) Weighted circuit noise power in dB referred to 3.16pW (-85dBm) which is 0dBa.
Use of weighting indicated in parenthesis as required.

2. dBa — (F1A) Weighted circuit noise in dBa measured on a line by a noise measuring set with F1A weighting.
Note: 1mW of a 1kc mod. tone reads +85dBa, but the same white noise power (300-3400cps) will read +82dBa due to frequency weighting.

3. dBa — (HA1) Weighted circuit noise power in dBa measured across a 302 type receiver with HA1 receiver weighting.

4. dBa0 — Circuit noise power in dBa referred to or measured at a point of zero relative transmission level (0dBr or OTLP).
Note: It is preferred to convert circuit noise readings from dBa to dBa0 as this makes it unnecessary to know or state the relative transmission level at point of actual measurement.

5. dBm — Power in dB relative to 1mW.

6. dBm0 — dBm referred to or measured at a point of zero transmission level.

7. dBmp — (dBm psophometrically weighted) Unit of noise power in dBm measured with psophometric weighting. Conversion as follows:

$dBm(psoph) = 10 \log_{10} pWp - 90 = dBa - 84 = dBm - 2.5$ (for flat noise 300-3400cps).

8. dBm0p — Circuit noise in dBm0 measured on a line with a noise measuring set having psophometric weighting.

9. dBr — dB relative to point of zero transmission level.

10. dBrn — (Decibels above reference noise) Weighted circuit noise power in dB ref. 1pW (-90dBm) which is 0dBrn. Type of weighting indicated in parenthesis.
Note: a) With 'C' message weighting, a 1mW 1kc tone will read +90dBrn, but the same power with white noise randomly distributed over a 3kc band (300-3400cps) will read +88dBrn.
b) With 144 weighting a 1mW 1kc tone will read +90dBrn, but a 3kc band of white noise will read +82dBrn due to the different frequency weighting.

11. dBrn — (144-line) Weighted circuit noise power in dBrn, measured on a line by a noise measuring set with 144 line weighting.

12. dBrn (144-receiver) Weighted circuit noise power in dBrn measured across the receiver of a subset with a 144-receiver by a noise measuring set with 144-receiver weighting.

13. dBrn or dBrnc (C-message) Weighted circuit noise power in dBrn, measured on a line by a noise measuring set with C message weighting.

14. dBrncO Noise measured in dBrnc referred to zero transmission level point. (OTLP)

15. dBrn (f_1 - f_2) Flat noise power in dBrn, measured over a frequency band between frequencies f_1 and f_2 (eg. 3kc flat).

16. OTLP Zero test level point (=0dBr), point of zero relative transmission level.

17. Psophometric Voltage or "Psophometric p.d." Circuit noise voltage measured on a line with psophometric weighting (CCIF 1951) applied.
Note: a) Do not confuse with psophometric emf, which is the emf of a generator or line with 600 ohm impedance. This is numerically double the psophometric voltage.
b) Psophometric voltage to dBmp conversion.
dBm(psoph) = 20 $\log_{10}$ V - 57.78
(V in psophometric millivolts)

18. pW (Picowatt equal to 10^{-12} watt or -90dBm) A unit of absolute power used for both weighted and unweighted noise.
10 $\log_{10}$ pW = dBm -90

19. pWp (pW psophometrically weighted) Noise power measured in picowatts via a CCIF psophometric filter.
pWp = 0.56pW (for flat noise 300-3400cps)

NOTE: See Fig. 2. for direct conversion of noise measuring units.

A.4 MULTI-CHANNEL AMPLIFIERS

Load Rating Theory of Multi-Channel Amplifiers

In a perfect multi-channel carrier telephone system each channel would be entirely free from interference produced by the energy present in the other channels. Since all the channels are amplified by the same repeaters, which as a practical matter cannot have perfectly linear characteristics nor be free from crosstalk effects, this ideal may be approached but never completely realized.

The inter-channel interference must be kept below a value which will be satisfactory for the grade of transmission concerned; further reduction is uneconomic.

Recommendations by DCA and CCIR for maximum values of interchannel interference are given commencing on page 19.

Single and Multi-channel Amplifiers

In a single channel amplifier, the loading depends only on the channel input, the ratio of peak to RMS signal is about 19dB with speech inputs (See Fig. 3). The effect of non-linearity in an amplifier carrying a single channel signal is to produce harmonic and intermodulation distortion of the channel signal only.

In a multi-channel amplifier the loading depends upon:

a) The number of active channels.

b) Talker volume averaged out over the number of active channels.

c) The presence of pilot signals required to synchronize the carrier equipment.

d) High level 'ringing' tones, used to establish initial communication.

There is a diversity factor which reduces the per channel loading as the

number of channels increases. As a result, the ratio of peak to the RMS value of the signal tends to 13dB when there are more than 60 active channels (See Fig. 5).

The distortion components falling into a given channel are generally unrelated to the signal in that channel; they are due to the loading on the other active channels since the distortion introduced on the channel signal itself is small by comparison. As a result, these components cannot be regarded as distortion of the channel signal, but rather as random interference or noise.

Multi-Channel Instantaneous Voltage Distribution

Fig. 4 shows the variation in peak to RMS voltage of a multi-channel signal as the number of active channels are varied. It can be seen that when N is greater than 16, the "normal" or gaussian distribution curve has a very similar shape to the telephone channel curves. This is also the distribution curve of gaussian or White Noise.

Multi-Channel Peak Factor

As discussed previously, as the number of active channels increase, the peak to RMS ratio of the multi-channel signal varies from 19dB for a single channel to 13dB when there are more than 60 active channels. Fig. 5 shows the variation in peak factor from 1 to 1000 active channels.

It should be noted that the peak to RMS ratio of gaussian noise is also 13dB. The characteristics of multi-channel signals and gaussian noise are such that the only way that their amplitude can be expressed, is in terms of amplitude probability. This is obtained by measuring the percentage of time that the peak value exceeds the RMS value by a given number of dB. (See Fig. 6). The peak factors quoted refer to measurements for 0.001% of time.

Activity Coefficient With Telephone Loading

With normal telephone conversation loading of a multi-channel system, none of the channels have a continuous input applied because:

a) When a subscriber is talking, his correspondent is listening.

b) The subscriber does not talk continuously, there will be punctuation pauses.

c) A system is usually designed so that there are channels in reserve even during 'busy hour' conditions.

The activity coefficient of a system is the fraction of the system capacity that is being actively used at a given time. Values quoted were measured statistically for greater than 1% of time. (As a practical point this is also the time interval normally chosen for noise loading level calculations). It will be noted that systems having few channels have the highest activity coefficient, this occurs because the averaging effect between channels is less.

Table 1. shows the variation in activity coefficient from 12 to 2700 channel systems.

TABLE 1.
Activity Coefficient

Number of Channels		Activity Coefficient
Nominal, N	Active, n	k
12	7	0.58
24	11	0.47
60	23	0.38
120	41	0.34
240	77	0.32
600	180	0.30
960	288	0.30

NOTE: The activity coefficient of systems greater than 600 channels is a constant (0.3 from CCIR), although Holbrook and Dixon quote 0.25 as their measured figure.

Activity Coefficient With Data Loading

With data or teleprinter loading of a multi-channel system the activity coefficient is much higher than with telephone loading. The trend is to assume 100% loading at all times.

Mean Power Level of the Multi-Channel Signal

a) With Telephone Loading ....

CCIR recommend two standard equations to approximate to the complex signal mean power curves produced by Holbrook and Dixon; these are:

For systems with less than 240 channels

$$P_M = -1 + 4 \log_{10} N \text{ dBm0}$$

For systems with greater than 240 channels

$$P_M = -15 + 10 \log_{10} N \text{ dBm0}$$

where P_M = Mean power of the multi-channel signal and

N = Nominal number of channels

These equations allow for variation in activity coefficient and multi-channel peak factor, they were derived empirically from actual measurements of multi-channel systems (see Holbrook & Dixon reference).

b) With Data Loading ....

The US military standard equation for data loading is:

$$P_M = -5 + 10 \log_{10} N \text{ dBm0}$$

This applies to all values of N.

c) Per Channel Loading ....

To calculate the effective per channel load of the three previous equations, the total power (P_M) should be divided by the number of channels (N). They become:

$P_c = -1 - 6 \log_{10} N$ dBm0 (where P_c = channel signal power)

for N less than 240

$P_c = -15$ dBm0 for N greater than 240

$P_c = -5$dBm0 for military loading

NOTE: The equations mentioned in a, b and c above are shown on Fig. 7

A.5 COMMUNICATION SYSTEM MODULATION PLANS.

a) Groups (12 Channel Translation Assembly)

A Group is a set of twelve telephone channels. Each channel is allocated a bandwidth of 4kc which includes the telephone channel bandwidth of 300 to 3400cps plus a guard band on either side. The total band occupied by twelve channels is then 48kc. The channels can be arranged to have either a "direct" or "inverted" frequency spectrum as indicated in Fig. 8.

Twelve channels arranged with a direct frequency spectrum are called an Erect Group (type 'A'), while twelve channels with an inverted spectrum are called an Inverted Group (type 'B'). This is illustrated in Fig. 9.

b) Super-Groups

A Super-group consists of five groups of the same sense, placed side by side without gaps in the frequency spectrum. This constitutes a 60 channel system which is the building block from which higher capacity systems are assembled. Fig. 10 illustrates a Super-group and Fig. 11 a standard 600 channel arrangement of 10 Super-groups.

c) Master-Groups

A 300 telephone channel arrangement of 5 super-groups is called a Master-group, this is illustrated in Fig. 12.

d) Super-Master-Groups

This is a 900 channel modulation system consisting of 3 master-groups which is illustrated in Fig. 13.

Modulation Plans for 4, 6 and 12mc Basebands

Fig. 14 shows modulation plans for various system capacities including suggested methods of transmitting television signals in 6mc baseband systems, also TV plus multi-telephone channels in 12mc systems.

A.6 D.C.A. SYSTEM NOISE RECOMMENDATIONS.

The following values are measured using noise loading techniques.

a) D.C.A. Trospheric Scatter Reference Circuits

The median of hourly median values of noise from all sources on any channel of a system composed of tropospheric scatter hops in tandem over a 6000 nautical mile reference circuit shall not exceed 25,000 pWp (38 dBaO F1A weighted) at a point of zero relative level during time block 2.

Time block 2 is defined as 1300 to 1800 hours local time, November to April. The median noise power shall be divided such that 5,000 pWp is assigned to the multiplex equipment and 20,000 pWp to the transmission media.

The allowable transmission media noise in a section of length L nautical miles, is:

$$\text{Noise} = \frac{L}{6{,}000} \times 20{,}000 \text{ pWp}$$

The total noise over a 6,000 nautical mile reference circuit shall not exceed 316,000 pWp more than a cumulative $\frac{L}{6{,}000}$ x 0.1% of time block 2.

Allocation of Noise Components

The following allocation of allowable median noise to various parts of the D.C.S. Reference tropospheric scatter or microwave line of sight circuits, shall be followed unless different distributions are dictated by particular requirements:

Multiplex Equipment	5000 pWp
One Link	
Channel translation	345 pWp
Group modem equipment (2)	140 pWp
Super-group modem equipment (3)	180 pWp
Through group filter and AGC equipment (3)	150 pWp
Total for 1 link =	815 pWp
Total for multiplex equipment for 6 links	4890 pWp

A.6 D.C.A. SYSTEM NOISE RECOMMENDATIONS.

b) The 20,000 pWp median noise assigned to the transmission media shall be derived in equal parts from the two principal sources, thermal and intermodulation, thus allowing 10,000 pWp thermal and 10,000 pWp intermodulation noise.

Noise in Real Circuit (less than 1,000 nautical miles)

The psophometrically weighted noise power excluding multiplex equipment noise, at a point of zero relative level in the audio channels of a real troposcatter hop of length L nautical miles, where L is less than 1,000 nautical miles and whose composition does not differ appreciably from the D.C.S. Reference Circuit, shall not --

1) Exceed 3.33 L pWp median during time block 2.

2) Exceed 136,000 pWp more than a cumulative $\frac{L}{1,000}$ x 0.02% of time block 2.

Noise in a Real Circuit (1,000 to 6,000 nautical miles)

The psophometrically weighted noise power excluding multiplex equipment noise, at a point of zero relative level in the audio channels of a real troposcatter hop of length L nautical miles, where L is between 1,000 and 6,000 nautical miles and whose composition does not differ appreciably from the D.C.S. Reference Circuit, shall not --

1) Exceed 3.33 L pWp median during time block 2.

2) Exceed 316,000 pWp more than a cumulative $\frac{L}{6,000}$ x 0.1% of time block 2.

DCA Microwave Line of Sight Reference Circuits.

The total noise from all sources on any channel of a system composed of line of sight hops in tandem over a 6,000 nautical mile reference circuit shall not exceed 25,000 pWp psophometrically weighted (38dBa F1A weighted) at zero relative level, during the worst hour of the month of poorest transmission. The noise power shall be divided such that 5,000 pWp is assigned to the multiplex equipment and 20,000 pWp to the transmission media. The

allowable transmission media noise in a section of length L nautical miles is found by the following:

$$\text{Noise} = \frac{L}{6{,}000} \times 20{,}000 \text{ pWp}$$

The total noise over a 6,000 nautical mile reference circuit shall not exceed 316,000 pWp (49 dBaO) 1 minute mean value more than a cumulative 0.01% of the worst month. For a portion of the system L nautical miles in length, the total noise shall not exceed 316,000 pWp more than a cumulative $\frac{L}{6{,}000} \times 0.01\%$ of the worst month.

Single Hop Performance (line of sight)

The psophometrically weighted noise power, excluding multiplex equipment noise, at a point of zero relative level in the audio channels of a real line of sight hop of length L nautical miles, where L is less than 1,000 nautical miles and whose composition does not differ appreciably from the D.C.S. Reference Circuit, shall not --

1) Exceed 3.33 L pWp median during the worst hour of the worst month.
2) Exceed 316,000 pWp more than a cumulative $\frac{L}{1{,}000} \times 0.002\%$ of the time during the worst month.

Tandem Hop Performance (1,000 to 6,000 nautical mile line of sight)

The psophometrically weighted noise power, excluding multiplex equipment noise, at a point of zero relative level in the audio channels of a real line of sight system of length L nautical miles, where L is between 1,000 and 6,000 nautical miles, and whose composition does not differ appreciably from the D.C.S. Reference Circuit shall not --

1) Exceed 3.33 L pWp median during the worst hour of the worst month.
2) Exceed 136,000 pWp more than a cumulative $\frac{L}{6{,}000} \times 0.01\%$ of the time during the month of poorest transmission.

Noise Allocation in Open-Wire Systems (less than 1,000 nautical miles)

The permissible weighted noise power at the receiving end of a 1,000 nautical mile 12 channel open-wire hypothetical reference circuit shall not exceed 14,800 pW at a point of zero relative level (35.7dBa). Of this quantity, not more than 2,500 pW shall be contributed by terminal multiplex equipment, leaving an allowance of 12,300 pW for the terminal and intermediate repeaters and the open-wire line. The allowance of 12,300 pW may be broken down into; repeater (terminal and intermediate) 1,800; line crosstalk 7,000; atmospheric, power and telegraph interference 3,500. The above figure of 12,300 pW for 1,000 nautical mile of line is equivalent to an allowance of 12.3 pW per nautical mile compared to 4.9 pW per nautical mile for cable systems.

Noise Allocation in Coaxial Cable Circuits

The total mean weighted noise in the band occupied by any standard channel (300 to 3,400cps) shall not exceed 3pW psophometrically weighted times the length of the cable route in nautical miles. These values shall be measured over the coaxial sub-system at a point of zero relative level.

Noise Allocation in Circuits Carrying Television Signals

1) Weighted Noise. Random (uniform) noise ratio, DAP picture/DAP noise, shall be greater than 30dB where the noise is weighted in accordance with curve E of Document 35 of the CCITT.
2) Impulsive Noise. The impulsive (short duration slow repetition) noise ratio shall be greater than 25dB (DAP picture/DAP weighted noise).
3) Pattern Noise. The pattern noise ratio shall be greater than 50dB (DAP picture/DAP weighted noise) up to 1mc falling to not less than 30dB at the highest frequency.

A.7 NOISE LOADING TECHNIQUES

Simulating the Multi-Channel Signal with White Noise

In Section A.4 (Multi-Channel Amplifiers) it was shown that the statistical properties of gaussian or white noise are very similar to those of the complex multi-channel signal when there are more than 16 active telephone channels. As a result, it is a legitimate measuring technique to use "white noise" to simulate the multi-channel signal.

The required noise power to simulate N channels can be obtained from the CCIR equations shown on page 17 which are:

$P_N = -1 + 4 \log_{10} N$ dBm0 for N less than 240 channels

$P_N = -15 + 10 \log_{10} N$ dBm0 for N greater than 240 channels

and $P_N = -5 + 10 \log_{10} N$ dBm0 for military loading

where P_N = Noise power required to simulate complex signal power due to N telephone channels.

Noise Bandwidth

To test a communication system with noise loading it is necessary to limit the bandwidth of the noise to that of the system baseband. The range of baseband frequencies that occur can be seen from Section A.5

This is accomplished in Marconi noise loading sets by applying the white noise to a high pass filter to define the lower end then to a low pass filter to set the high frequency end of the noise spectrum.

Measurement of Intermodulation and Thermal Noise Using White Noise Loading

As shown in Section A.4, the effects of distortion in multi-channel amplifiers is to produce interference resembling random noise in the measured telephone channel. The method used with white noise loading to measure distortion and other noise components is to place a number of "quiet" slots in the

white noise spectrum before it is applied to the baseband of the system. The resulting "spillover" noise into the noise slot is measured at the baseband output of the remote receiver. The noise measured will be due to distortion effects and thermal noise of the entire communication system from the baseband input of the sending station to the baseband output of the remote receiver.

If three measuring slots are used, one near the low end, one in the middle and one at the upper end of the baseband, the results obtained will show the distribution of spurious components over the entire baseband. Fig. 15 shows a typical NPR distribution curve of a 600 channel system.

Noise Power Ratio

Marconi noise loading sets measure the intermodulation and thermal noise of a system in terms of NPR (noise power ratio).

NPR is defined as follows: Noise in a test channel with ALL channels loaded with white noise --- to --- noise in the test channel with all channels except the test channel fully noise loaded, expressed in dB.

NPR Conversion to pWp, etc.

The measured NPR can be converted to pWp, dBa, dBrn, etc. as shown in Section C. (See Fig. 2 and Fig. 16)

B. SYSTEM NOISE PARAMETERS.

When a system is noise loaded the spurious noise power measured in a test channel or slot is equal to the sum of the spurious noise power components of the noise loaded portion of the system that fall into the slot frequency.

B.1 SOURCES OF SPURIOUS NOISE.

a) Thermal Noise

This is a constant for a receiver of given noise factor and bandwidth at constant input level. However, during fading conditions the gain of the receiver will change due to AGC action, as a result the thermal noise at the receiver output will change as the input RF level changes (see Section B.2) Diversity reception is used to minimize fading effects.

b) Intermodulation Noise in FM and SSB Systems

This is caused by non-linearity in various parts of the system including the following:

1) Amplitude and intermodulation distortion in baseband and multiplex circuits.
2) Crosstalk in multiplex equipment.

.In FM systems the following additional sources of intermodulation noise occur:

3) Transmitter non-linearity.
4) Mis-match in aerial feeders.
5) Multipath effects in the propagation medium.
6) Receiver non-linearity.

B.2 THRESHOLD IN FM AND SSB RECEIVERS.

From Fig. 17 it can be seen that in FM communication systems there is a definite "knee" to the curve plotting output signal to noise ratio versus RF input level. This point is called the FM threshold.

If the receiver is operated below this level there will be a drastic increase in thermal noise at the receiver output. Consequently FM systems are usually designed so that only under extreme fading conditions will the input level fall to the threshold point.

Two techniques are used to maintain the effective RF input above threshold:

1) Diversity reception, where the path of best transmission is automatically selected.
2) Threshold extension. It is possible to lower the threshold point 2 to 3dB by compressing the deviation ratio of the received signal. This is accomplished by applying anti-phase FM to the local oscillator in the receiver (See Florman & Tory reference).

Fig. 17 shows also that SSB multi-channel systems have a superior signal to noise ratio at very low input levels. However, the adoption of threshold extension makes the two methods almost equal at low levels and of course, FM systems have a much higher signal to noise ratio than SSB at high RF input levels. SSB systems come into their own below 30mc where FM systems are unusable because of multipath reception and large bandwidth requirements.

B.3 PRE- AND DE- EMPHASIS.

In an FM receiver, the output voltage from the FM detector is directly proportional to frequency deviation (a necessary condition for demodulation to occur). As a result, if white noise with uniform (ie. rectangular) frequency distribution over the baseband range is applied to the FM detector, the demodulated noise output will have a triangular distribution.

This property of FM is used to improve the received signal to noise ratio by using pre-emphasis in the FM modulator circuits and corresponding de-emphasis at the receiver.

Pre-emphasis is accomplished with a CR or LR circuit which produces an FM deviation/modulation frequency characteristic proportional to modulation frequency. A compensating CR circuit (de-emphasis) at the receiver, restores an overall uniform modulation frequency response.

The signal to noise ratio of the system is improved because the de-emphasis circuit reduces the effective noise bandwidth of the baseband circuits and the remaining noise components have more uniform distribution over the baseband. Fig. 18 illustrates the signal to noise improvement obtained with this method. The spurious noise components that are reduced by de-emphasis include those due to intermodulation, showing that the effect of distortion products are also reduced by this technique.

B.4 OVERALL SYSTEM NOISE.

From the previous paragraphs it will be seen that the spurious noise in an overall system is due to two principle causes:

1) Thermal noise.
2) Intermodulation noise, from all sources.

The amount of thermal noise is controlled by: transmitter RF power output, location and gain of antennas, receiver noise factor and depth of fading experienced in a given communication link.

The intermodulation noise level is due to the amplitude of the complex modulation signal.

Systems are designed so that the magnitude of these components meet the recommendations of CCIR and DCA. (See A.6)

C. MEASUREMENTS USING NOISE LOADING TECHNIQUES

C.1 NPR MEASUREMENT

a) Baseband to Baseband

This is the best known application of white noise loading. As described in Section A.7, the noise signal is bandlimited to suit the baseband of the system and three test frequencies are chosen at the low, middle and upper ends of the baseband.

The noise is applied to the baseband input of the transmitter at a level of:

$P_n = -1 + 4 \log_{10} N$ dBm0 for N less than 240 channels

$P_n = -15 + 10 \log_{10} N$ dBm0 for N greater than 240 channels

$P_n = -5 + 10 \log_{10} N$ dBm0 for military loading (any number of channels)

See Section A.7 for further details of power level.

The Marconi Noise Receiver is connected to the baseband output of the remote system receiver and tuned to the frequency of the slot filter chosen.

The NPR is now measured by noting the change in attenuator setting of the Noise Receiver needed to maintain constant reading on the output meter when the slot filter is switched into circuit.

b) Baseband to Telephone Channel

The baseband slot frequencies chosen to test a given system often translate directly to a telephone channel frequency depending upon the modulation plan used.

When this occurs, the NPR between the baseband input to the transmitter and the remote telephone channel can be measured directly by connecting a VTVM to the channel output point.

The difference in VTVM reading when the slot filter is switched "out" then "in" is the channel NPR.

This is a convenient method of separating the de-multiplex equipment's spurious noise contribution from the baseband to baseband noise (measured with conventional noise loading).

c) Baseband to Super-Group, etc.

The technique of the previous paragraph may be extended to measure the NPR of the baseband input to super-group or group, etc. output by connecting a noise receiver tuned to the translated group or super-group frequency output point.

It is important in this case to use a noise receiver fro the NPR measurement because of the stringent selectivity requirements of the output indicator with wide band noise applied.

C.2 INDIVIDUAL CHANNEL NOISE LOADING.

As discussed previously, conventional noise loading measures the NPR of a system from the baseband input of the transmitter to the baseband output of the receiver. This means that the I.M. products and crosstalk effects of the multiplex equipment are not included in the measurement and have to be measured separately.

An alternative noise loading test for low capacity systems is to load each telephone channel input with noise over the range 300-3400cps. The multiplex will heterodyne the individual noise signals to load the complete baseband of the system. If a VTVM or noise meter is connected to a telephone line

output at the remote receiver and the noise loading from that channel removed, the difference in readings on the test meter with loading "on" then "off" will be the NPR of that channel. The NPR read using this method will be that of the entire system, line-in to line-out.

Per Channel Noise Power

It was shown on page 17 how to calculate the per channel noise power (eg. -15dBm0 per channel for N = 240). These are the levels at which noise power is applied to each telephone channel for individual loading so that if for comparison, a conventional baseband to baseband measurement is made, the effective noise loading will be the same.

C.3 MEASUREMENT OF CROSSTALK IN MULTIPLEX EQUIPMENT.

Crosstalk in low capacity multiplex equipment can be measured by connecting the multiplex back to back then applying say, twelve independent noise sources (300-3400cps eg. Marconi Model 7816) to the multiplex input.

Crosstalk and intermodulation distortion products of the multiplex can be separated as follows: Crosstalk is usually caused by insufficient channel filtering. If an NPR test is made with only the two adjacent channels loaded, the reading will be due to crosstalk. This can be verified by repeating the NPR measurement with two channels loaded with a guard band either side of the test channel, ie. if testing channel #6, load channels #5 and #7 for crosstalk measurement. To separate I.M. and spurious noise contributions repeat measurement with channels #4 and #8 loaded.

C.4 MEASUREMENT OF INTERMODULATION DISTORTION COMPONENTS IN MULTIPLEX EQUIPMENT.

Intermodulation distortion causes components from all channels to contribute to the noise in the idle channel. It can be separated from crosstalk by loading all channels except the quiet channel and its two adjacent channels. As discussed, crosstalk is contributed mainly by the adjacent channels and since in a normal multiplex system crosstalk is considerably greater than intermodulation for levels less than overload, it is necessary to avoid loading the adjacent channels to provide a guard band.

For the following text, refer to Fig. 19 "Graphical Presentation of Individual Channel Loading".

As the input level is increased, the noise in the quiet channel will increase fairly linearly until the overload point is reached when a rapid increase takes place. By switch selecting more, or fewer, channels on the Model 7816 Generator, measurements can be made using different activity coefficients.

A typical test of a multiplex system back to back shows three regions:

1) Idle noise (no load), due to thermal noise and coupling from multiplex pilot tones.
2) Light Loading. Noise level increasing at a low rate as the per channel loading is increased. This is caused mainly by crosstalk from those channels immediately adjacent to the quiet channel.
3) Heavy Loading. Harmonic components and intermodulation distortion due to heavy per channel loading are reflected in the steeper slope of the curve. Intermodulation distortion in the quiet channel can be produced by overloading any of the channels unlike crosstalk which is usually traceable to the adjacent channels.

C.5 NPR MEASUREMENTS OF SYSTEM COMPONENTS.

Baseband amplifiers etc. can be tested directly using noise loading techniques by applying white noise at the correct level to simulate dynamic working conditions. Since individual amplifiers, etc. may have a high NPR (eg. greater than 60dB), it may be necessary to allow for the NPR of the white noise set itself to ensure accurate results. (See Fig. 20)

It is important that when the back to back NPR of the test set is measured, the output and input levels used for the test are the same as will be used to measure the system component's NPR.

C.6 BASEBAND INTRINSIC NOISE RATIO.

The Baseband Intrinsic Noise Ratio of a system is a measure of idle noise due to thermal noise, carrier leaks, spurious FM in oscillators, etc. BINR is defined as noise in a test channel with ALL channels noise-loaded --- to --- noise in the test channel with all noise loading removed.

The difference between measured NPR and BINR indicates the amount of spurious noise in the system caused by intermodulation distortion and crosstalk.

In addition to a BINR measurement of idle noise, it is normal practice to examine the baseband signal with a spectrum analyzer or selective voltmeter to ensure that the BINR reading is not in error due to the presence of spurious signals (eg. excessive carrier leaks, etc.)

C.7 CONVERSION OF NPR TO SINGLE CHANNEL SIGNAL TO NOISE RATIO.

a) With Baseband Noise Loading

To relate the NPR reading of a noise loading test to equivalent channel signal to noise ratio or test tone level to noise, the following conditions apply:

$$N = P_G \times \frac{B_T}{B_G} \times \frac{1}{P_R} \quad \text{where}$$

N = Noise power ratio (numeric)

P_G = Power output from noise generator or power applied to receiver (mW)

B_T = Effective bandwidth of a telephone channel (300-3400cps)

B_G = Bandwidth of noise generator (kc)

P_R = Noise power due to intermodulation and system noise in the telephone channel

Re-writing the previous expression:

$$P_R = \frac{P_G}{N} \times \frac{B_T}{B_G} \quad \text{or}$$

$$\frac{1}{P_R} = \frac{N\ B_G}{P_G\ B_T}$$

$$\therefore \frac{T}{P_R} = \frac{T.N.B_G}{P_G\ B_T} = \frac{N \times B_G}{B_T} \times \frac{1}{P_G / T} \quad \text{where}$$

T = Test Tone Level of a telephone channel (mW)

$$\therefore 10 \log_{10} \frac{T}{P_R} = 10 \log_{10} N + 10 \log_{10} \frac{B_G}{B_T} - 10 \log_{10} \frac{P_G}{T} \quad \text{or}$$

Test Tone Level to Noise Ratio in dB

$= \text{NPR dB} + 10 \log_{10} \frac{B_G}{B_T}$ -dB ratio of noise generator power test tone level.

(The last term is commonly called the Noise Loading Ratio and is given by the CCIR loading equations $P_N = -15 + 10 \log_{10} N$, etc.)

NOTE: Fig.16 shows a graphical method of NPR to S/N ratio conversion.

The telephone channel whose signal to noise ratio is calculated by this method is the channel that the baseband slot frequency is translated to by the multiplex equipment.

In practice, the measured signal to noise ratio of a channel will be lower than that calculated because of additional crosstalk and intermodulation effects in the multiplex equipment. (See Marconi Model 7816 Twelve Channel Noise Generator)

b) With Individual Channel Noise Loading

This is simpler to calculate than with baseband noise loading because the noise powers are applied directly to the telephone channels

S/N = NPR - (Per channel noise loading)

eg. In a 'military' loading system the NPR is measured to be 40dB

Per Channel Noise Loading = -5dBm0

∴ S/N = 45dB

C.8 CONVERSION OF SIGNAL TO NOISE RATIO TO CHANNEL NOISE.

When the measured NPR of a system has been converted to channel signal to noise ratio, the channel noise can be calculated as follows:

a) dBa0 Noise Units

The term dBa refers to F1A weighted noise measurement above a reference noise level of -85dBm, ie. 0dBa = -85dBm (at 1kc). However, when white noise is applied to an F1A weighting filter it is attenuated by 3dB

0dBa = -85 +3 = -82dBm (white noise applied)

∴ To convert S/N ratio to dBa0

dBa0 = 82 - (S/N)

b) dBrnc Noise Units

The term dBrnc refers to 'C' message weighted noise measurements above a reference noise level of -90dBm, ie. 0dBrnc = -90dBm (at 1kc).

When white noise is applied to a 'C' message weighting filter it is attenuated by 1.5dB

0dBrnc = -88.5dBm (white noise applied)

∴ To convert S/N ratio to dBrnc0

dBrnc0 = 88.5 - (S/N)

c) Picowatts of Noise Power

1pW = 10^{-12} watts or 0dBm = 10^{9} pW

Picowatts of noise power are usually measured with psophometric weighting. When white noise is applied to a CCIR psophometric weighting filter, it is attenuated by 2.5dB (almost the same as F1A weighting).

Assuming 0dBm0 = 0dBm at the point of measurement, to convert S/N ratio to picowatts

$$pW = \frac{10^{9}}{\text{Anti } \log_{10} S/N} \quad \text{or} \quad pWp = \frac{10^{9} \times 0.56}{\text{Anti } \log_{10} S/N}$$

If 0dBm0 is not equal to 0dBm, the noise power should be corrected to suit the difference in level.

NOTE: Fig. 2 is a conversion chart of noise measuring units.

D. ALLIED MEASURING TECHNIQUES

D.1 OUT-OF-BAND TESTING.

White Noise Loading of a multi-channel communications system provides a rapid means of testing the goodness of the system. However, when these tests are being made, normal traffic cannot be handled and must be switched to a different communication channel. Where this is not permissable, out-of-band testing may be used.

This is a method of continuously monitoring the intermodulation distortion and system noise of a multi-channel system without interrupting normal traffic. In this arrangement normal traffic constitutes the loading of the system and a noise receiver continuously monitors the noise in a channel which is about 10% outside the normal baseband. Band stop filters at the out-of-band frequencies are placed permanently in circuit at the transmitter to ensure that nothing is sent out on these channels. The noise receiver indication is then due only to system intermodulation and noise.

If a pen recorder is used to record the receiver meter reading, it will show the variations of intermodulation and system noise with time. Where a three channel recorder is available, the second pen may be used to monitor traffic level and the third pen the AGC voltage of the microwave or link receiver. Variations in noise reading can then be related to their cause and suitable adjustments made.

If it is required to calibrate the pen recorder reading in power, a noise generator may be used to give a standard noise input to the receiver. The noise generator power seen by the receiver will be:

$$10 \log_{10} \frac{B_R}{B_G} + P_G$$

where B_R = Receiver bandwidth (1.2kc with Marconi 1249 series, 1kc with Marconi 2090)
B_G = Generator bandwidth
P_G = Noise Generator power in dBm

The power due to system intermodulation and noise is then measured by

adjusting the noise receiver attenuator until the same meter reading is attained with traffic connected as was obtained with the noise generator connected. The resulting power due to system intermodulation and noise

$$P_S = 10 \log_{10} \frac{B_R}{B_G} + P_G + N \text{ dBm}$$

where N is the difference in attenuator setting between the standardized and the spurious noise inputs.

It is convenient to calibrate the output power meter of the standardizing noise generator in dBm/kc, eg. -126dBm per kc. Then since the effective bandwidth of a Marconi Model 2090 Noise Loading Set is 1kc, once the receiver gain has been standardized the previous expression simplifies to:

$$P_S = -P_N + N \text{ dBm (with Model 2090 and where } P_N = \text{dBm/kc of noise generator)}$$

When using Marconi 1249 series Noise Loading Test Sets, the expression becomes: $P_S = P_N + N - 10 \log_{10} \frac{1.2}{1}$ dBm

$$= P_N + N - 0.8 \text{dBm}$$

D.2 VIDEO TAPE RECORDER MEASUREMENTS

A tape recorder can be regarded as a single channel wideband amplifier. The bandwidth of the noise generator should be chosen to suit the bandwidth of the recorder.

To measure the NPR of a wideband tape recorder, the noise power should be applied at a level 8 to 10dB below the maximum sine wave level that can be applied without excessive distortion. The NPR measured can be converted to S/N ratio by adding the noise loading factor (8 to 10dB) to the NPR reading.

The effects of wow, flutter, etc. will be included in the NPR measurement because any spurious FM effects in the recorder will tend to narrow the effective received slot width and therefore increase the noise applied to the noise receiver.

E. MARCONI NOISE LOADING TEST SETS

E.1 MODEL 1249 SERIES.

This was the first noise loading test set made by Marconi Instruments; the current model is a transistorized unit, Model 2090.

Model 1249 consists of three units - Noise Generator, Band Stop Filter Unit and Noise Receiver.

The spectrum of the noise generator extends from 12 to 4188kc (ie. suitable for loading 12 to 960 channel systems). A special version of the generator (1249B/3) covers the range 12 to 5564kc for 1200 channel systems.

The noise receiver has nine pre-tuned channels. Changing the receiver channels involves re-wiring the RF tuning unit of the receiver.

E.2 MODEL 2090

This is the latest Marconi White Noise Test Set. It consists of two units - Noise Generator complete with plug-in and switchable high, low and band stop filters and the Noise Receiver, which uses plug-in channel coils to suit the band stop frequencies chosen.

Each unit weighs 25 lbs (less filters) which makes the instrument very portable. The noise spectrum extends from 12kc to 12.5mc (ie. suitable for loading 12 to 2700 channel systems).

E.3 MODEL 7816 TWELVE CHANNEL NOISE GENERATOR.

Model 7816 is the first instrument that has been designed and built by Marconi Instruments in the USA.

Designed originally for noise loading low capacity systems (eg. tropo-scatter, SSB, etc.) it has also been found very useful with multiplex equipment, separating crosstalk from intermodulation, etc.

Twelve independent noise sources are used, each with a bandwidth of 300 to 3400cps. The output level per channel is adjustable from 0 to -32dBm in 2dB steps.

F. RECOMMENDED HIGH, LOW AND BAND STOP FILTERS.

F.1 CCIR RECOMMENDATIONS FOR HIGH, LOW AND BAND STOP FILTERS.

The requirements for the high and low pass filters are combined in the specifications of the noise band characteristic. Within any band the RMS noise level must not vary by more than 1dB, and outside the band the noise should be more than 25dB down at all frequencies greater than 10% above and 20% below the band limit frequencies.

The band stop filter specification is as follows:- The noise suppression must exceed 80dB over at least a 3kc band and should exceed 3dB at the frequencies 0.02F + 4kc from the center frequency F kc. The shape of the characteristics should be such that when any three band stop filters are simultaneously brought into circuit (and the noise bandwidth is not less than 240kc) the errors in measurement as compared with a measurement carried out with a perfectly uniform source and an indefinitely narrow stop banc, must not exceed 1dB.

Fig. 21 illustrates the noise band characteristics and Fig. 22 the band stop filter response of the CCIR recommendations.

F.2 FILTERS FOR MARCONI MODEL 2090 WHITE NOISE TEST SET.

Table 2. gives a list of filter frequencies available for Model 2090 White Noise Test Set. They are based on CCIR recommendations for various system capacities.

In certain cases special filters can be designed and built to suit customer requirements.

TABLE 2.

Typical Filter Frequencies for Various Capacities

No. of Channels	Band Limits		In-Band Slots			Out-of-Band Slots	
	High Pass	Low Pass	Lower	Center	Upper	Lower	Upper
12	12 kc	60 kc	27 kc	40 kc	50 kc	—	—
24	12 kc	108 kc	40 kc	70 kc	105 kc	—	—
36	12 kc	156 kc	40 kc	70 kc	105 kc	—	—
48	12 kc	204 kc	40 kc	105 kc	185 kc	—	—
60	12 kc	252 kc	40 kc	185 kc	245 kc	—	—
60	60 kc	300 kc	70 kc	185 kc	270 kc	50 kc	331 kc
120	60 kc	552 kc	70 kc	270 kc	534 kc	50 kc	607 kc
240	60 kc	1,052 kc	70 kc	534 kc	1,002 kc	50 kc	—
300	60 kc	1,300 kc	70 kc	534 kc	1,248 kc	50 kc	1,499 kc
600	60 kc	2,660 kc	70 kc	1,248 kc	2,438 kc	50 kc	3,200 kc
960	60 kc	4,028 kc	70 kc	2,438 kc	3,886 kc	50 kc	4,715 kc
960	316 kc	4,188 kc	534 kc	2,438 kc	3,886 kc	270 kc	4,715 kc
1,200	316 kc	5,564 kc	534 kc	3,886 kc	5,340 kc	—	—
1,800	316 kc	8,204 kc	534 kc	3,886 kc	8,002 kc	—	—
2,700	316 kc	12,388 kc	534 kc	3,886 kc	12,150 kc	—	—

Filter frequencies (and characteristics) correspond to CCIR Recommendation 294 (Warsaw 1956-Los Angeles 1959) also ratified by Defense Communications Agency DCA CIR 175-2A April 1963.

G. NOISE LOADING LOW CAPACITY SYSTEMS

The CCIR recommendations for the insertion loss of band stop filters are given as follows:- The shape of the characteristics should be such that when any three band stop filters are simultaneously brought into circuit (and the noise bandwidth is NOT LESS THAN 240kc) the errors in measurement as compared with a measurement carried out with a perfectly uniform source and an indefinitely narrow stop band, must not exceed 1dB.

However, when testing systems having 60 (240kc baseband) or less channels, this recommendation does not apply and when one or more band stop filters are brought into circuit the noise power loss may be appreciable.

When making baseband to baseband NPR measurements it is usually permissable to allow for the insertion loss of the filter by increasing the noise power applied, to maintain a constant noise input to the system.

Table 3. gives the insertion loss of various Marconi band stop filters when used in low capacity systems. The dB figures quoted show the increase in noise power required from the noise generator when the filter is switched into circuit to maintain constant noise input to the system.

TABLE 3. POWER LOSS DUE TO THE INTRODUCTION OF BAND STOP FILTERS.

The following table gives the loss of power relative to the total power in the noise band. The ratio is quoted in dB's for 12, 24, 36, 48 and 60 channel systems.

	Loss in dB's					
Centre Frequency kc/s	*12-Channel System 12–60 kc/s*	*24-Channel System 12–108 kc/s*	*36-Channel System 12–156 kc/s*	*48-Channel System 12–204 kc/s*	*60-Channel System 12–252 kc/s*	*60-Channel System 60–300 kc/s*
14	0·8	0·4	0·25	0·2	0·15	—
27	1·1	0·5	0·3	0·25	0·2	—
34	1·7	0·8	0·5	0·35	0·3	—
40	2·1	0·9	0·6	0·45	0·35	—
50	1·7	0·8	0·5	0·35	0·3	—
56	1·6	0·85	0·55	0·4	0·3	—
70	—	1·1	0·7	0·5	0·4	0·4
105	—	1·2	1·15	0·8	0·65	0·65
135	—	—	0·55	0·4	0·3	0·3
152	—	—	0·6	0·45	0·35	0·35
185	—	—	—	0·55	0·45	0·45
245	—	—	—	—	0·45	0·45
270	—	—	—	—	—	0·55
290	—	—	—	—	—	0·5

H. REFERENCES AND ACKNOWLEDGEMENTS

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Fagot and Magne, Pergamon Press, New York

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3. Load Rating Theory for Multi-channel Amplifiers
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5. R.A.D.C 3009 (Interim MIL-STD-188)
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7. Radio Relay Systems, etc.
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8. dBa and Other Logarithmic Units
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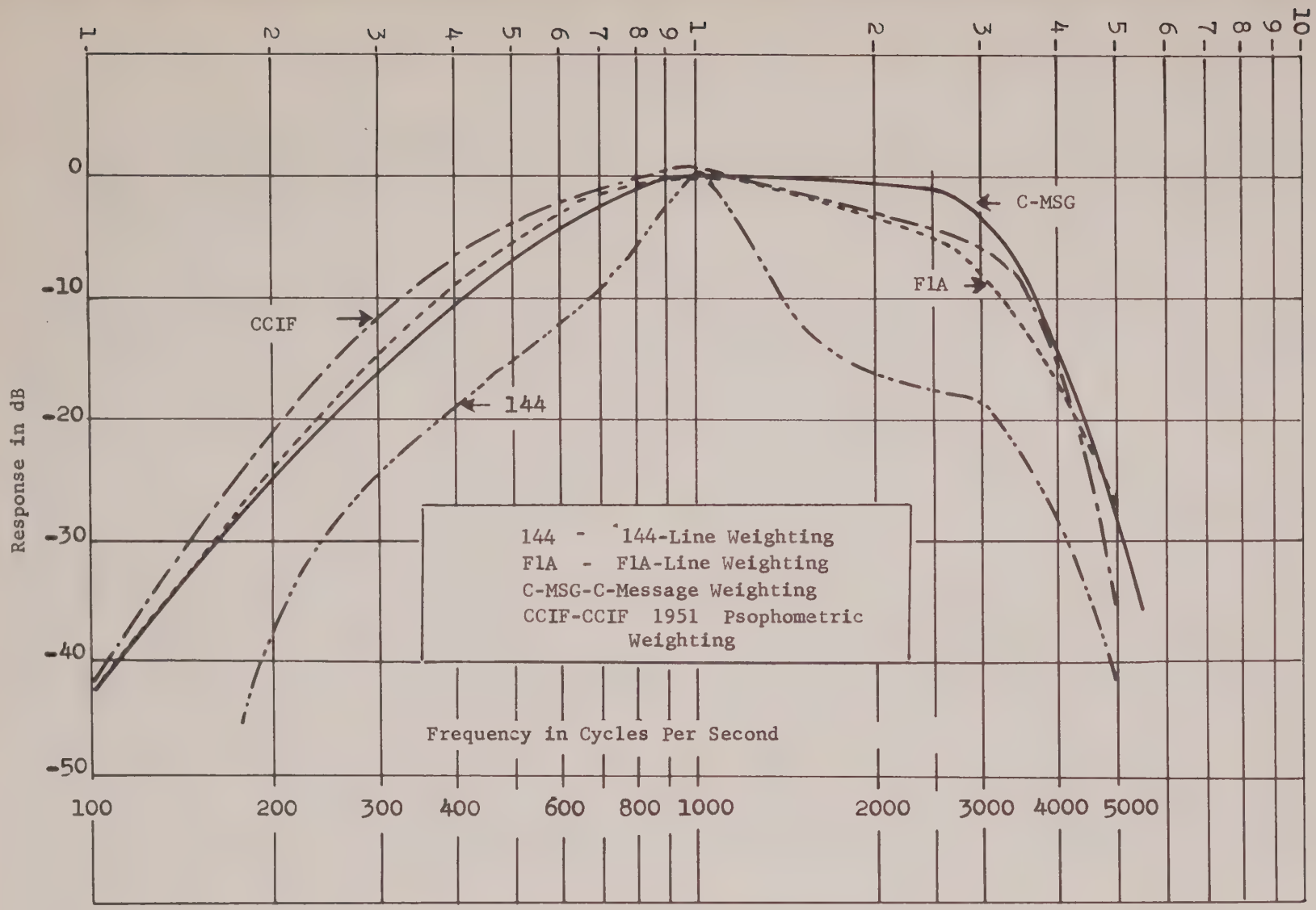
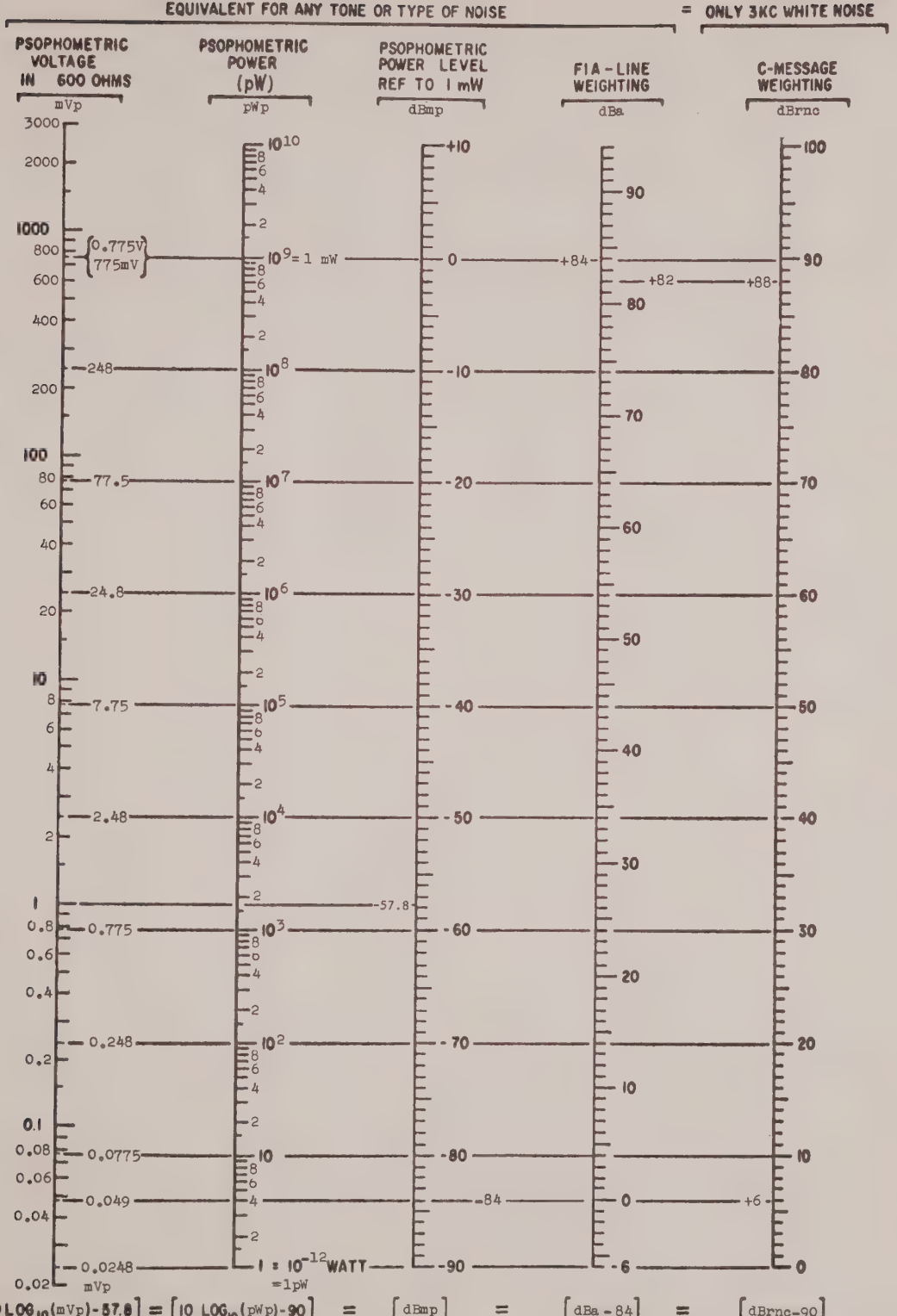


FIG. 1 LINE WEIGHTINGS FOR TELEPHONE MESSAGE CIRCUIT NOISE



$[20 \log_{10}(mVp) - 57.8] = [10 \log_{10}(pWp) - 90] = [dBmp] = [dBa - 84] = [dBrnc - 90]$

- BASIS FOR CHART CONSTRUCTION -

A. dBm, PSOPH. WTD. (dBmp) = dBa - 84

B. ONE mW UNWEIGHTED 3Kc WHITE NOISE READS +82 dBa = +88.5 dBrnc(C-MESSAGE), ROUNDED OFF TO: +88.0 dBrnc

C. ONE mW INTO 600 OHMS = 775mV = 0dBm = 10^{9}pW

READINGS OF NOISE MEASURING SETS WHEN CALIBRATED ON ONE MILLIWATT OF TESTTONE:

F1A - Line: AT 1000cps, READS +85dBa
C - MESSAGE: AT 1000cps, READS +90dBrnc
PSOPHOMETER (1951), 800cps, READS 0dBm

CONVERSION CHART: PSOPHOMETRIC, F1A AND C-MESSAGE NOISE UNITS

FIG. 2

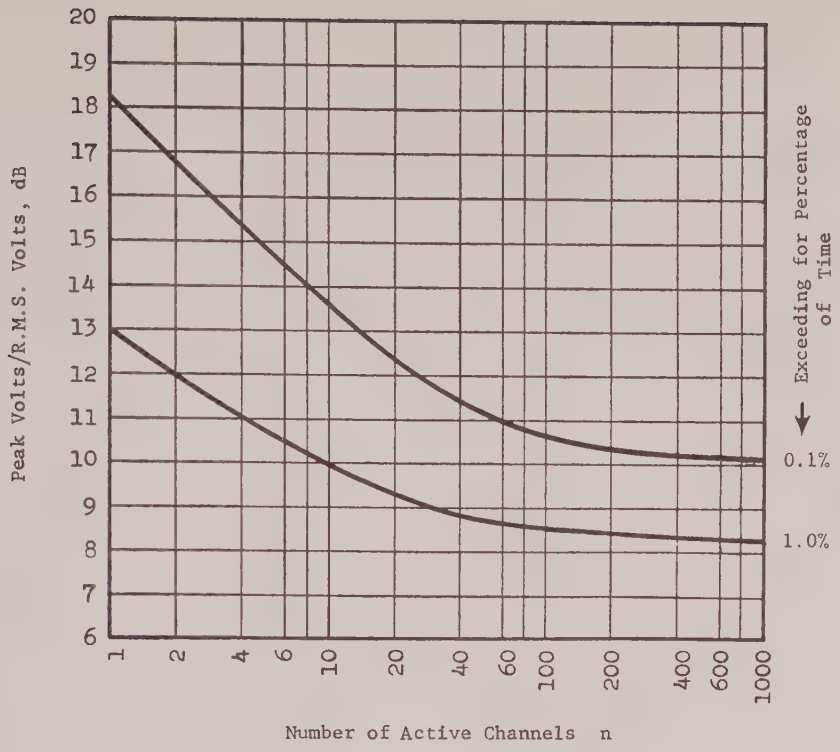


FIG. 3 PEAK/RMS VOLTAGE VERSUS NUMBER OF ACTIVE CHANNELS

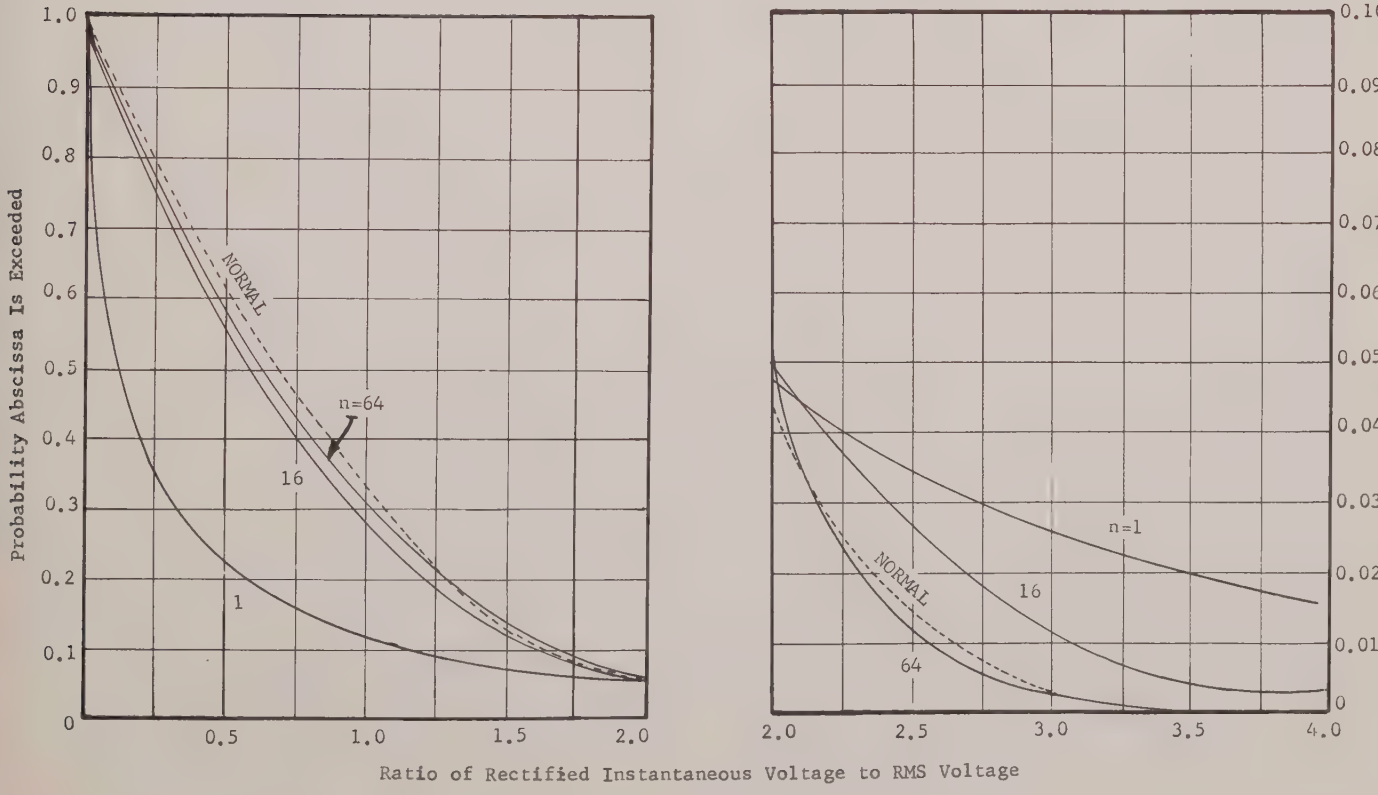


FIG. 4 INSTANTANEOUS VOLTAGE DISTRIBUTIONS FOR n TALKERS

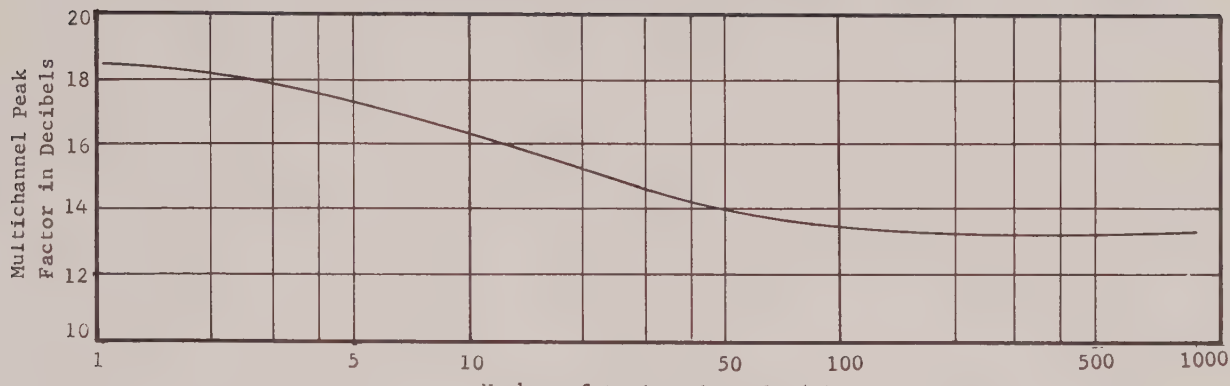


Fig. 5 MULTI-CHANNEL PEAK FACTOR FOR n ACTIVE CHANNELS

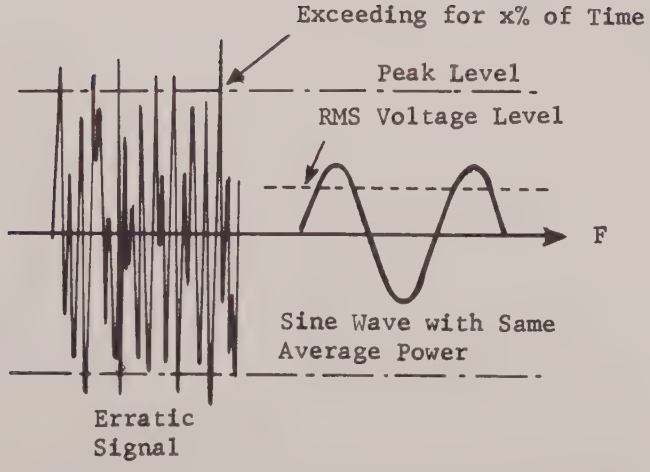


FIG. 6 ILLUSTRATION OF PEAK/RMS NOISE MEASUREMENT

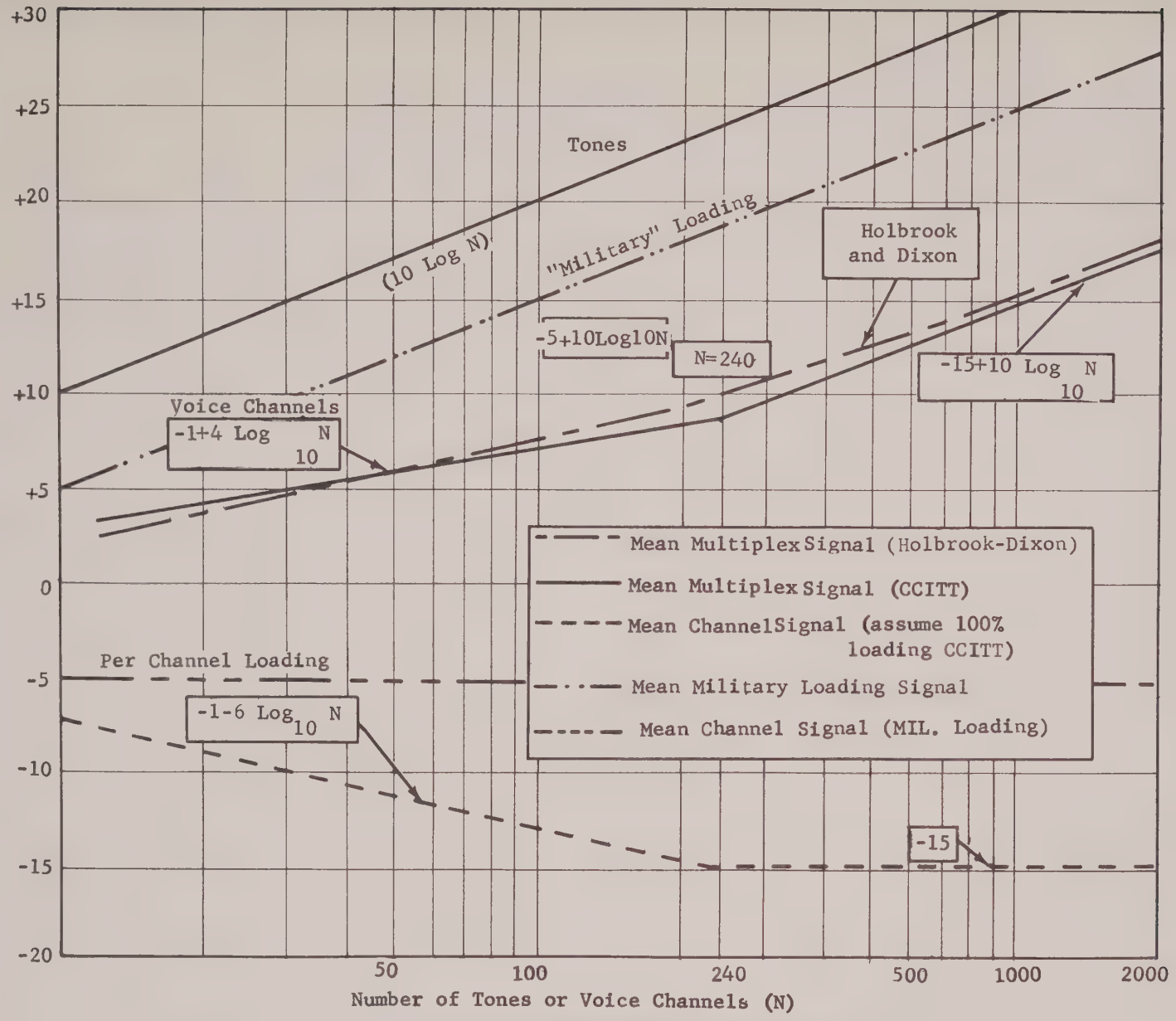


Fig. 7 MULTICHANNEL LOADING CURVES

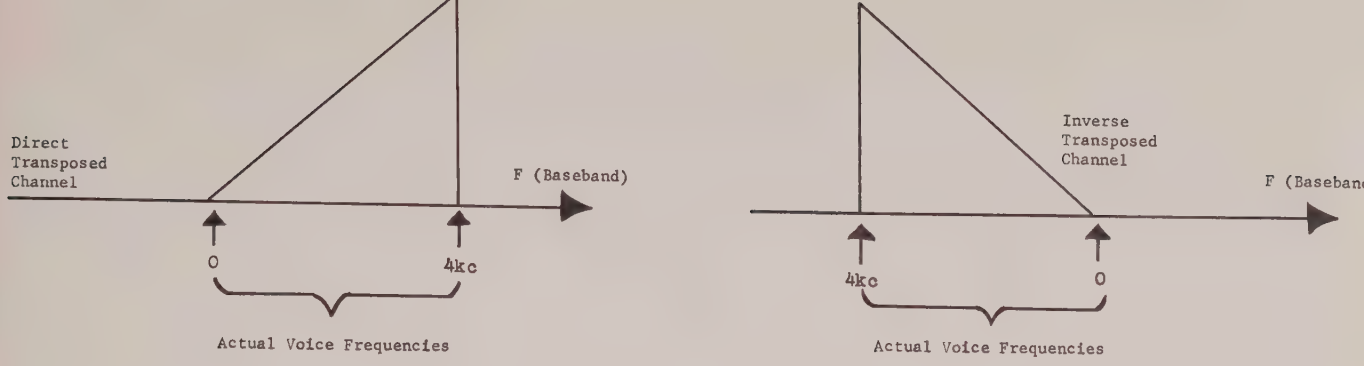


FIG. 8 DIRECT AND INVERSE TELEPHONE CHANNELS

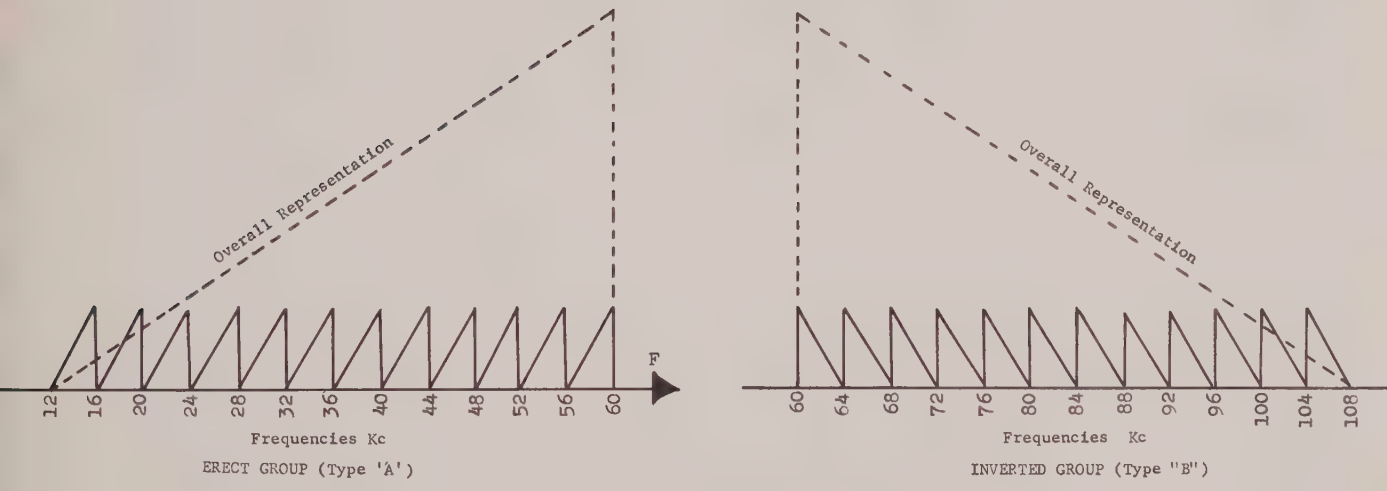


FIG. 9 ERECT AND INVERTED GROUPS

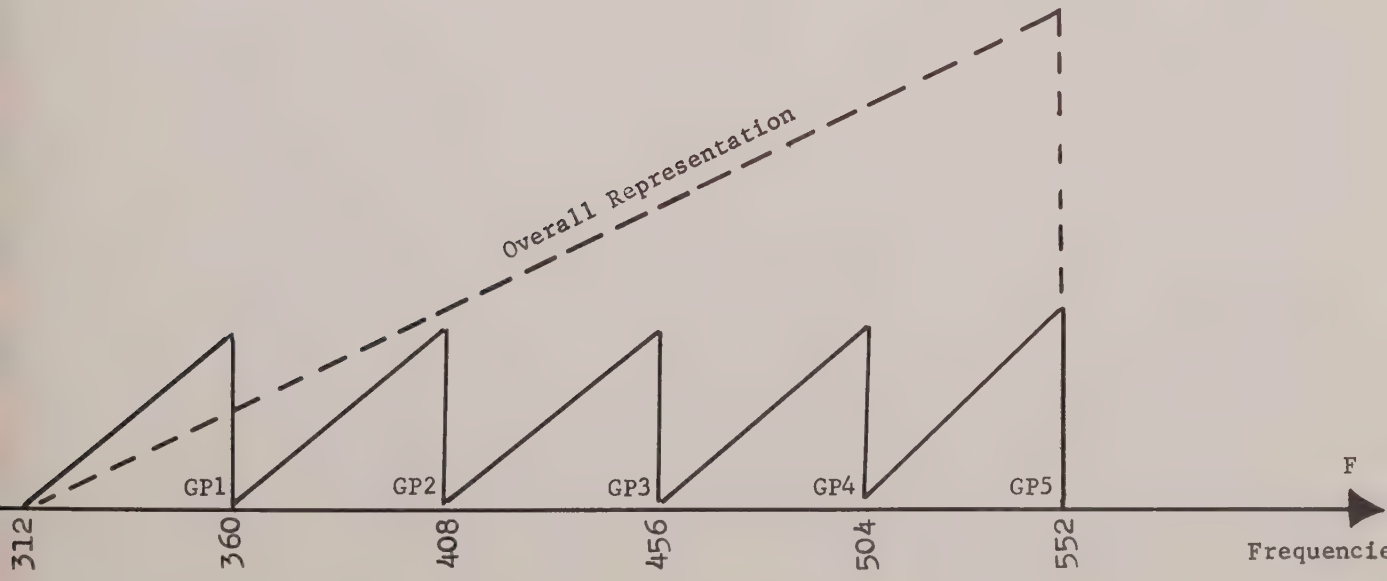
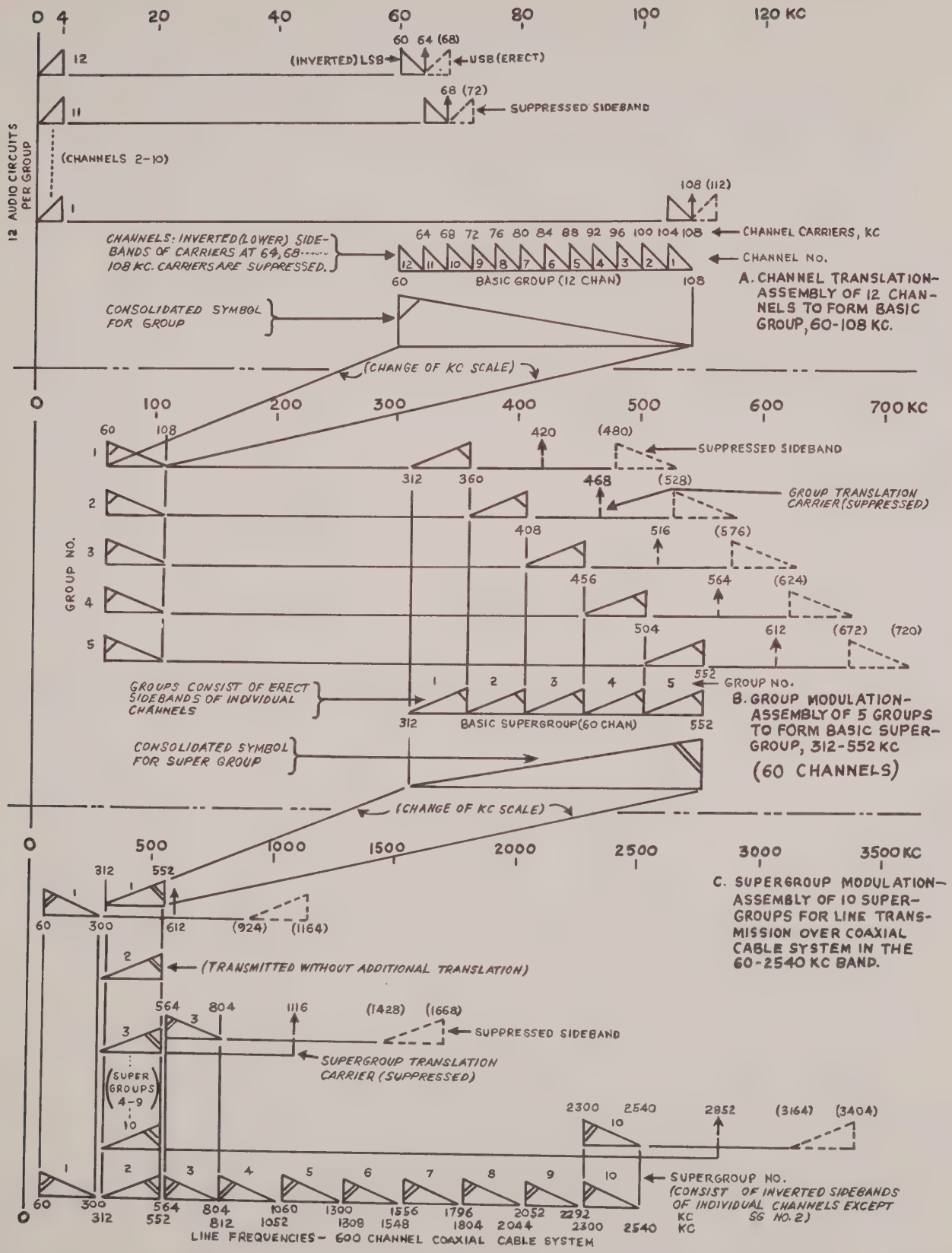


FIG. 10 SUPER GROUP


0 4 20 40 60 80 100 120 KC
60 64 (68)
12
(INVERTED) LSB
USB (ERECT)
68 (72)
11
SUPPRESSED SIDEBAND
(CHANNELS 2-10)
12 AUDIO CIRCUITS PER GROUP
108 (112)
1
CHANNELS: INVERTED (LOWER) SIDEBANDS OF CARRIERS AT 64, 68 ..... 108 KC. CARRIERS ARE SUPPRESSED.
64 68 72 76 80 84 88 92 96 100 104 108
CHANNEL CARRIERS, KC
12 11 10 9 8 7 6 5 4 3 2 1
CHANNEL NO.
60
BASIC GROUP (12 CHAN)
108
A. CHANNEL TRANSLATION-ASSEMBLY OF 12 CHANNELS TO FORM BASIC GROUP, 60-108 KC.
CONSOLIDATED SYMBOL FOR GROUP
(CHANGE OF KC SCALE)
0 100 200 300 400 500 600 700 KC
60 108
420 (480)
SUPPRESSED SIDEBAND
312 360
468 (528)
GROUP TRANSLATION CARRIER (SUPPRESSED)
408 516 (576)
456 564 (624)
504 612 (672) (720)
GROUP NO.
1 2 3 4 5
552
GROUP NO.
GROUPS CONSIST OF ERECT SIDEBANDS OF INDIVIDUAL CHANNELS
312
BASIC SUPERGROUP (60 CHAN)
552
B. GROUP MODULATION-ASSEMBLY OF 5 GROUPS TO FORM BASIC SUPERGROUP, 312-552 KC (60 CHANNELS)
CONSOLIDATED SYMBOL FOR SUPER GROUP
(CHANGE OF KC SCALE)
0 500 1000 1500 2000 2500 3000 3500 KC
312 552
60 300 612 (924) (1164)
C. SUPERGROUP MODULATION-ASSEMBLY OF 10 SUPERGROUPS FOR LINE TRANSMISSION OVER COAXIAL CABLE SYSTEM IN THE 60-2540 KC BAND.
(TRANSMITTED WITHOUT ADDITIONAL TRANSLATION)
564 804 1116 (1428) (1668)
SUPPRESSED SIDEBAND
SUPERGROUP TRANSLATION CARRIER (SUPPRESSED)
(SUPER GROUPS 4-9)
2300 2540 2852 (3164) (3404)
1 2 3 4 5 6 7 8 9 10
SUPERGROUP NO. (CONSIST OF INVERTED SIDEBANDS OF INDIVIDUAL CHANNELS EXCEPT SG NO. 2)
60 300 312 564 552 804 812 1060 1052 1300 1308 1556 1548 1796 1804 2052 2044 2292 2300 2540
KC KC
LINE FREQUENCIES - 600 CHANNEL COAXIAL CABLE SYSTEM

TYPICAL MODULATION PLAN FOR A 600 CHANNEL SYSTEM

FIG. 11

FIG. 12 BASIC MASTERGROUP

FIG. 13 BASIC SUPERMASTERGROUP

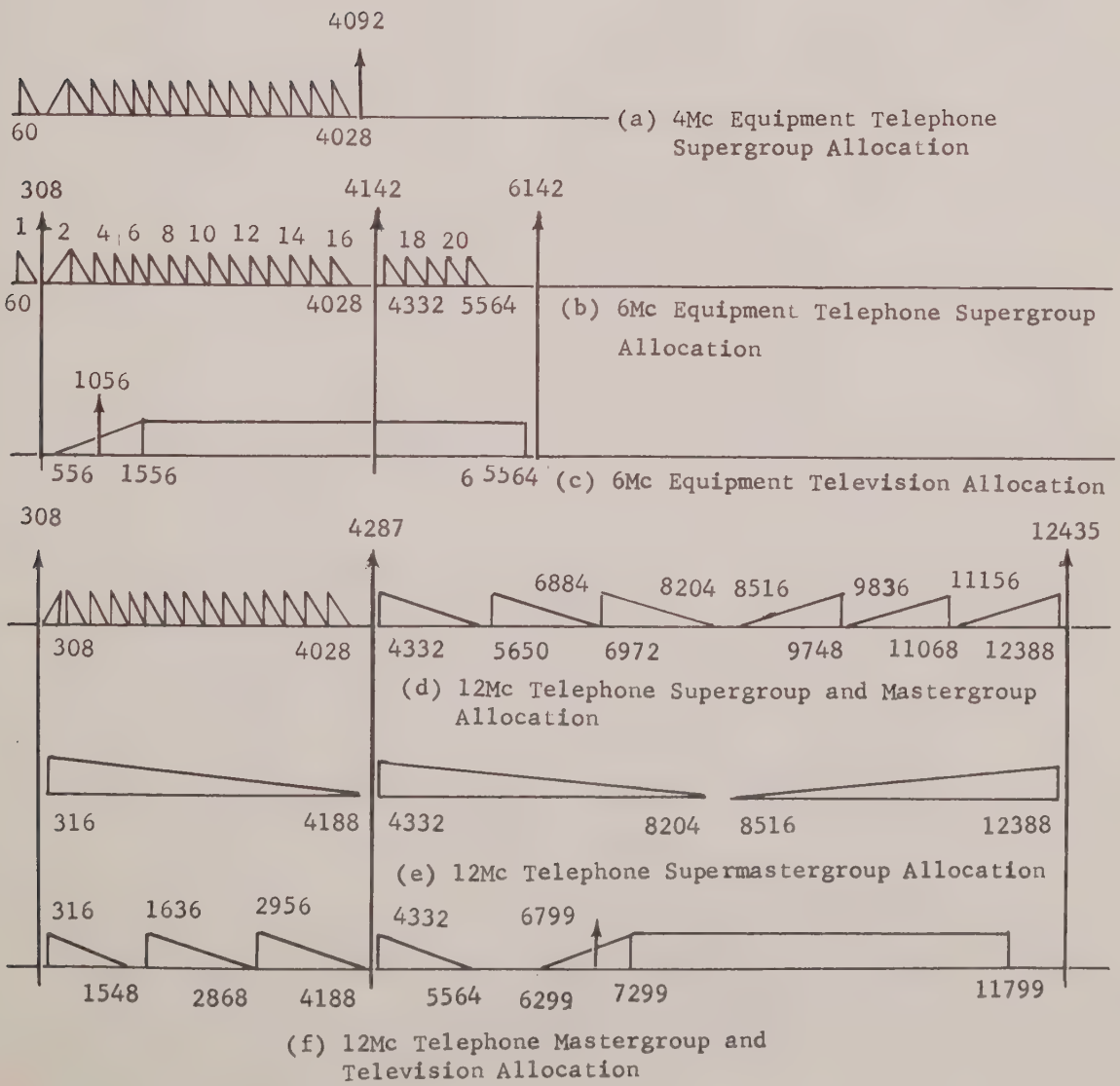


FIG. 14 - MODULATION PLAN FOR VARIOUS HIGH CAPACITY SYSTEMS

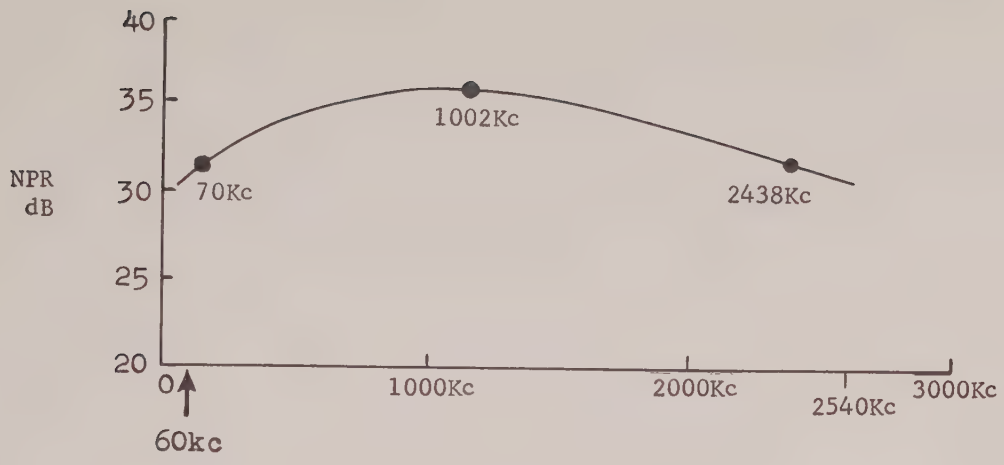


FIG. 15 TYPICAL NPR DISTRIBUTION CURVE

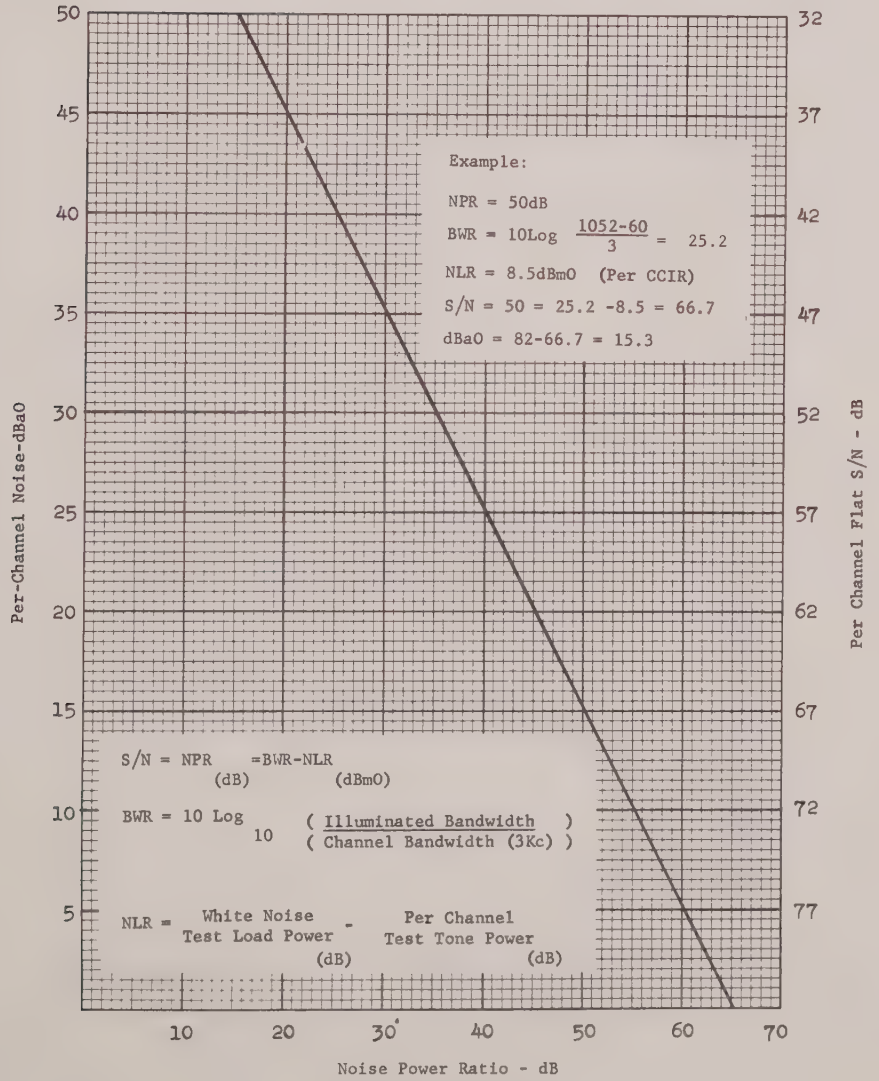


FIG. 16 GRAPHICAL CONVERSION OF NPR TO S/N
FOR A 240 CHANNEL SYSTEM

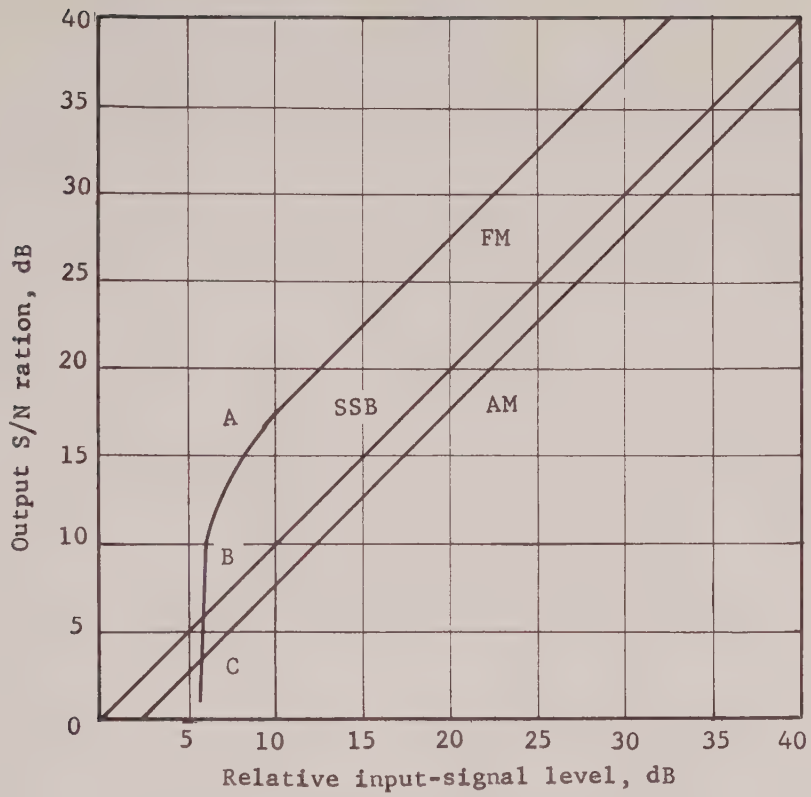
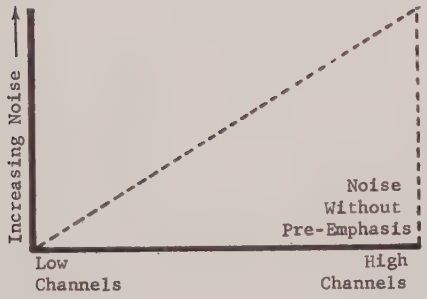


FIG. 17 COMPARISON OF SIGNAL-TO-NOISE RATIOS FOR AM, SSB and FM



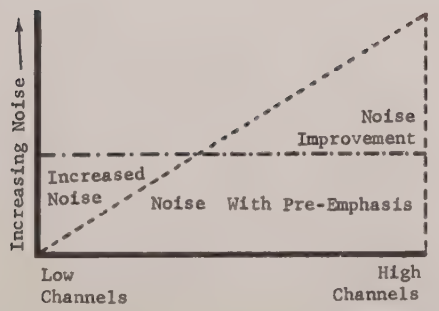


FIG. 18 EFFECTS OF PRE- DE-EMPHASIS

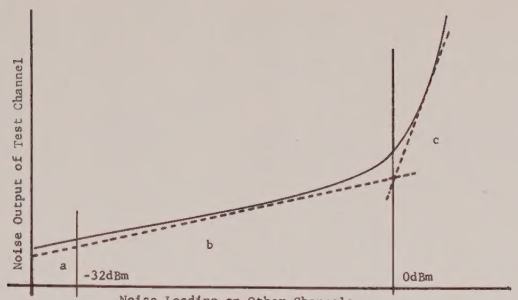


FIG. 19 GRAPHICAL PRESENTATION OF INDIVIDUAL CHANNEL LOADING

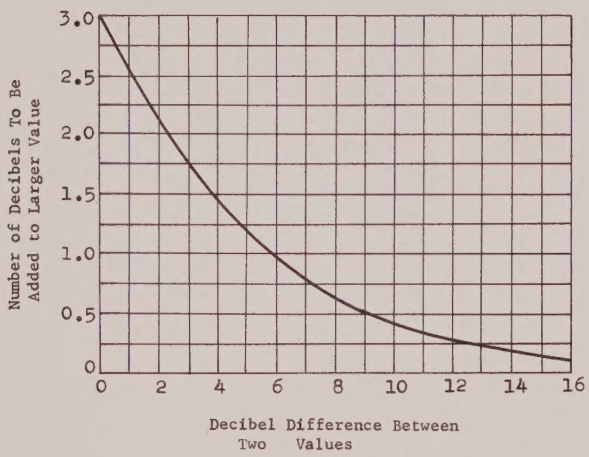


FIG. 20 CORRECTION FACTOR WHEN NPR OF TEST SET APPROACHES NPR OF SYSTEM

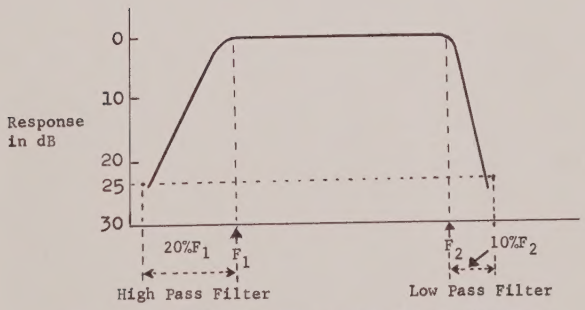


FIG. 21 CCIR RECOMMENDED FILTER LIMITED BANDWIDTH

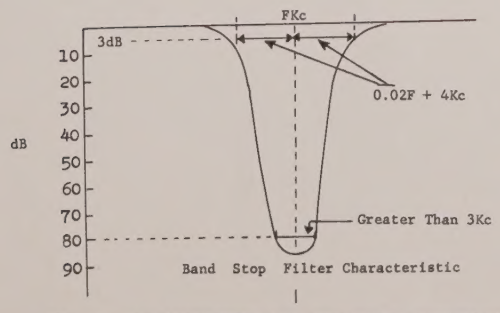


FIG. 22 CCIR RECOMMENDED BAND STOP FILTER CONFIGURATION

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